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Optimal protruding node length of bicycle seats determined using cycling postures and subjective ratings

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ABSTRACT

This study examined body posture, subjective discomfort, and stability, requiring the participants to ride a stationary bicycle for 20 min (cadence: 60 rpm; workrate: 120 W), using various combinations of two handle heights and five seat-protruding node lengths (PNLs). The results indicated that bicycle handle height significantly influenced body posture, and that seat PNL caused differences in the riders' subjective discomfort and stability scores. The various PNLs affected only the trunk angle (approximately 6°), but had significantly positive ($r = 0.994$, $p < .005$) and negative ($r = -0.914$, $p < .05$) correlations with the subjective discomfort rating for perineum and ischial tuberosity, respectively. When the participants were seated at PNL = 0 or 3 cm, cycling using dropped handles was less stable compared with using straight handles; however, the handle height did not affect the cycling stability when the PNL was ≥6 cm. The results suggest that a 6-cm PNL is the optimal reference for bicycle seat designs.

1. Introduction

Because of the rapid growth of bicycling communities in recent years, bicycles and riding activities have been researched. Previous studies have primarily focused on riding efficiency (Stone and Hull, 1995; De Vey Mestdagh, 1998), handlebar heights (Kolehmainen et al., 1989), and frame size (Richmond, 1994; Kautz and Hull, 1995). In recent years, the focus of bicycle-related research has gradually shifted to seat (or saddle) design (Groenendijk et al., 1992; Bressel et al., 2009). Chen and Yeh (2012) have observed that the subjective discomfort rating for the buttocks area is relatively higher than those for the other parts of the body. Some riders have quit cycling because of unbearable discomfort or harm caused by bicycle seats (Burke, 1994).

The contact between the seat and the buttocks is a critical cause of discomfort and pain. Groenendijk et al. (1992) showed that the pressure distribution on the seat is determined by how the pads support the pelvic bones. Richmond (1994) and Matheny (1995) indicated that handlebars that are set too low can induce compression neuropathy and certain overuse symptoms, as well as irritation of the labia in female cyclists and of the prostate in male cyclists. Nakamura et al. (1995) examined four long-period and long-distance bicycle-commuting Japanese male students and observed that a nodule had developed near each of their coccygeal regions and the shape corresponded to the saddle of the bicycle. Groenendijk et al. (1992) surveyed 900 cyclists, determining that 36% of men and 42% of women complained about their bicycle seat. The men complained of pain at the pelvic bone, an anaesthetized sexual organ, and pain in the perineal region. Four complaints were specific to female cyclists including painful pelvic bones, irritated genitals, burning skin, and a painful coccyx. Groenendijk et al. observed that discomfort for both men and women occurred even during short bicycle trips (3–10 km). Another study examining 453 cyclists showed that the most frequently mentioned complaints were saddle sores (35%), and more women than men experienced discomfort when riding a bicycle or when seated on a saddle (Christiaans and Bremner, 1998).

Previous studies on bicycle seats have primarily focused on analyzing traditional seats that exhibit protruding nodes (De Vey Mestdagh, 1998; Bressel and Larson, 2003; Bressel et al., 2007) or analyzing the seat pressure distribution for various commercial seats (Lowe et al., 2004; Sauer et al., 2007; Potter et al., 2008; Bressel et al., 2009). In summary, the protruding node length (PNL) is a crucial difference among various bicycle seats.

Differences in the PNL may influence a rider's comfort when cycling. Traditional seats with a long protruding node provide riding stability (Bressel et al., 2009). However, they increase the pressure on the perineal and groin regions, causing riders to extend

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their torsos far backward when cycling. In this case, because the proportion of the torso weight on the seat is increased, the pressure on the ischial tuberosity is also increased (Potter et al., 2008). Although nonprotruding node seats can minimize pressure to the anterior perineum (Lowe et al., 2004), and may be helpful in reducing seat injuries, they may also increase the risk of falling injuries if stability is compromised (Bressel et al., 2009). This may be because it is simple to slip off a seat that lacks a protruding node (Dickson, 1985); however, this is unacceptable by riders (Lowe et al., 2004). Bressel and Larson (2003) also determined that most riders felt that the seat was uncomfortable. Therefore, an appropriate PNL design is critical; however, previous studies on various riding postures and subjective ratings have compared only commercially available bicycle seats (Bressel and Larson, 2003; Bressel et al., 2009; Lowe et al., 2004). In addition to PNL, the design variables for bicycle seats vary substantially and have not been thoroughly researched in previous studies, causing the understanding of the effect of PNL on riding posture and subjective ratings to be limited.

In this study, we hypothesized that an optimal PNL may exist for traditional seats; furthermore, seats involving protruding nodes that enable maintaining a proper degree of body stability, reducing discomfort in the perineal region, and guiding the trunk to bend forward during riding, thereby lightening the load on the ischial tuberosity. In the experiment, we collected data regarding the body postures of riders, subjective discomfort ratings, and cycling stability after the participants rode a bicycle for 20 min, using various handle heights and seat PNL combinations to identify the optimal PNL.

2. Methods

2.1. Participants

We recruited 16 male university students to participate in this study. Their mean (SD) age was 23.7 (2.0) years, and the ages ranged from 21 to 26 years. Their mean (SD) height and weight were 172.5 (range: 168–181) cm and 66.2 (range: 60–75) kg, respectively. Table 1 shows the demographic data for 16 male participants. Participants who had a history of musculoskeletal injury or pain or cardiovascular problems were excluded. All participants maintained exercise habits and physical stamina, and bicycled regularly. Each participant agreed to avoid staying up late or using excessive energy during the experimental period. The participants were informed of the test procedures and were paid for their participation. Informed consent from all of the participants was obtained according to the regulations of the Ethics Committee of Chang Gung Memorial Hospital of Taiwan, which approved this study.

2.2. Experimental bicycle seats and handles

In the study, five seats comprising various PNLs were fabricated by a manufacturer of standard male-type bicycle seats (No: 6091010, Giant, Taichung, Taiwan). A stationary road bicycle (No. ESCAPE R1, Giant, Taichung, Taiwan) was mounted on a Cyclotron Bicycle Auto Trainer (Giant, Taichung, Taiwan). Except for the PNL, all other seat design factors remained unchanged (e.g., shape, material, and structure) for each participant. The seat inclination was controlled horizontally across experiment tests. The width of the seats was the commercially adopted 16 cm (Bressel and Cronin, 2005), and the PNL ranged from 0 to 12 cm, and each 3-cm interval was established as a level, as shown in Fig. 1. The handle heights were horizontally set at 0 cm and −16 cm, regarding the seat surface and height definitions of the standard straight and dropped handlebars, respectively (Chen and He, 2012).

Table 1
Demographics of the 16 male participants.

Items	Mean	Range
Age (years)	23.7	22.2–26.5
Stature (cm)	172.5	168.4–181.2
Body mass (kg)	66.2	60.8–75.1
Preferred saddle height (cm)	87.4	84.0–95.5
Cycling weekly distance (km)	26.8	10–75
Cycling regularly (times/week)	2.8	1–7

2.3. Posture recordings

The cycling posture of the participants was recorded as they rode a bicycle equipped with various PNL and handle combinations. Because the body joint angles in the sagittal plane were analyzed in this study, two-dimensional (2D) kinematics data for cycling were collected (Kolehmainen et al., 1989; Bressel and Larson, 2003; Schultz and Gordon, 2010). Before data were collected, four adhesive reflective markers and two stick markers were attached to the participants' body landmarks (i.e., tragus, acromial shelf, femoral greater trochanter, and the caudal-most point on the iliac crest) and skin surfaces of the spinal processes (the first lumbar and first sacral processes) on their dominant side, respectively (as shown in Fig. 2). The angles of head extension (HE) and pelvic tilt (PT), as well as the trunk angle (TA) and lumbosacral angle (LSA), were measured as suggested by Chen and Lee (1997). Each participant's external LSA (ELSA, formed by S1 and L1) was then used to calculate the internal LSA according to prediction models developed by Chen and Lee, which are expressed as follows:

$$\mathrm{IL}_1 = 0.9882 \times \mathrm{SL}_1 + 3.6274 \quad (R^2 = 0.968)$$

$$\mathrm{IS}_1 = 0.7339 \times \mathrm{SS}_1 + 29.6776 \quad (R^2 = 0.916)$$

where SL1 and SS1 are the external L1 and S1 stick marker angles, respectively. IL1 and IS1 are the internal angles. The LSA can be obtained by determining the formed angle of IL1 and IS1.

2.4. Subjective discomfort and stability rating

In this study, the subjective assessments were performed using a continuous visual analog scale (VAS, Bressel et al., 2009; Eungpinichpong et al., 2013). The scale was 100 mm in length and was modeled after the comfort scales and cycling stabilities developed by Mundermann et al. (2002) and Bressel et al. (2009), respectively. The VAS has been reported to be a reliable assessment of perception and is more precise than an ordinal scale that ranks responses (Gramling and Elliott, 1992; Mundermann et al., 2002). The left end of the scale was labeled *no discomfort at all* and the right end was labeled *extreme discomfort*. To improve the consistency of implementing the discomfort scale, we provided written instructions to each participant before they performed each test combination. The instructions were, "Please mark the line to indicate the relative discomfort of the test; the further to the right, the more uncomfortable the test was." The participants used a pen to complete ratings by marking locations along the scale that most accurately represented their feeling of discomfort after a trial. An analyst used a ruler to measure the distance from the *no discomfort at all* anchor to the location of a mark, and data were measured for analysis. The levels of discomfort experienced in each cyclist's wrist, neck, lower back, perineum, and ischial tuberosity were

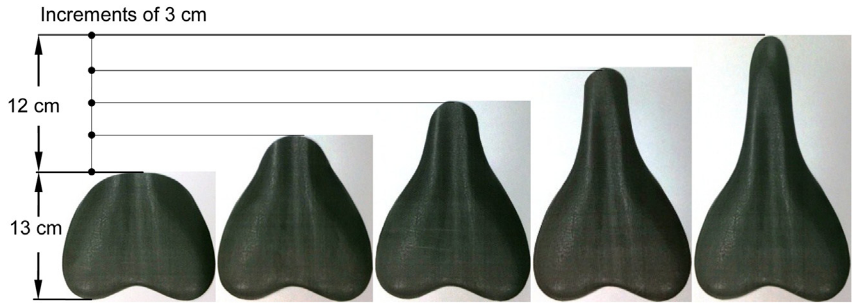

Fig. 1. Schematic diagram of the five types of PNL seat cushions used in this study.

rated. Regarding cycling stability, the scale ranged from *not unstable at all* to the *most unstable seat imaginable*. After the participants rode a bicycle for 20 min, they were immediately asked to provide the discomfort and stability scores.

2.5. Experimental design

The 16 participants simulated cycling for 20 min for each of 10 test combinations (2 handle types [straight and dropped] × 5 seat PNLs [0, 3, 6, 9, and 12 cm]). This test time was assumed to be sufficient because discomfort increased most rapidly during the first 10 min of cycling (Abayanayaka, 1993). During testing, the participants pedaled the stationary bicycle at a resistance equivalent to a power output of 120 W at a cadence of 60 rpm. At the end of each ride, the subjective discomfort for various body parts and stability rating scores were immediately self-reported by the participants. The participants repeated each experimental combination twice on distinct days; thus, the reliabilities between the trials were analyzed for each dependent variable. The order of implementing the bicycle setup combinations and repetition was random. Consequently, 320 data records were collected in this study. To analyze the motion data, the participant posture was randomly measured thrice within the last cycling minute (i.e., the 19th–20th minute) as the crank arm was pedaled in a forward horizontal position. These three measurements were averaged for use in subsequent analyses.

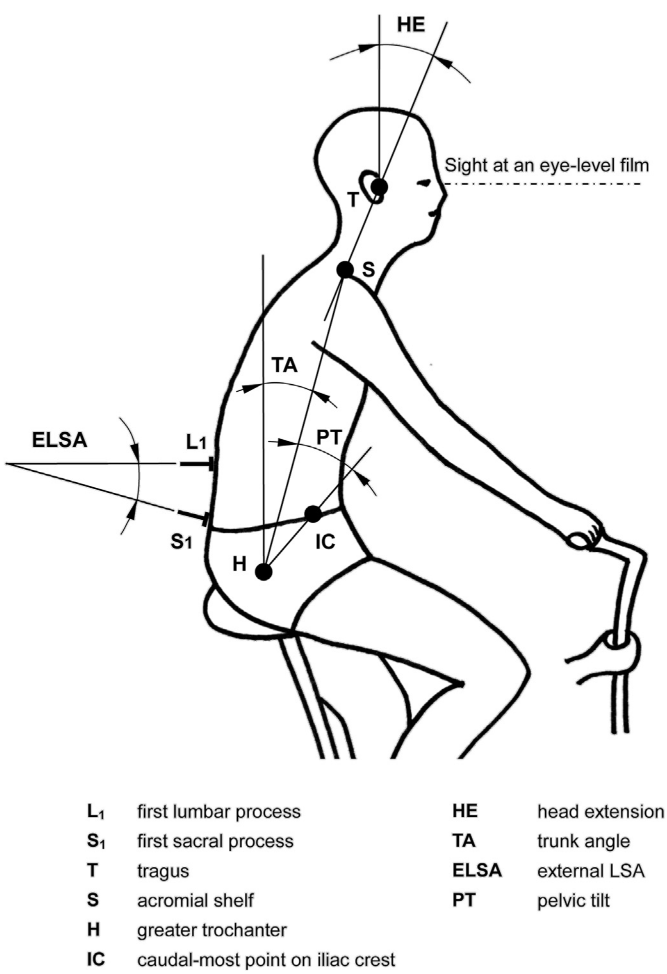

Fig. 2. Schematic diagram of body joint angles in a cycling posture.

2.6. Experimental procedure

The participants were required to wear cycling shorts. Prior to the experiment, the participants warmed up for 5 min to acclimate to the cycling tests. Each participant adjusted the seat to the most comfortable height (Potter et al., 2008), and the preset seat height was determined by referring to Nordeen-Snyder (1977), who suggested that the seat height was set to 100% of the rider's trochanteric leg length. The experimenter then established the handle height based on the height of the seat surface (0 and −16 cm). The workload (120-W) was preset using the Cyclotron Bicycle Auto Trainer, and the pedaling cadence (60 rpm) was controlled using a metronome to maintain the target pedaling rate. After the experiment was initiated, a motion analysis system (Qualisys MacReflex, Sweden), positioned approximately 5 m from the participant and perpendicular to the participant's sagittal plane, recorded the 2D marker positions (resolution = 1:30,000 in the camera field of view at 60 Hz) of the reflective markers on the participants; these angles were calculated using image processing software (Qualisys MacReflex, Sweden). A calibration frame (2.5 m × 2.5 m; four calibration points) was used to construct a validated 2D plane by using the motion system, yielding measurement errors within ±0.5°. To prevent the results from being affected by fatigue, the participants underwent a maximum of two tests per day with a minimum of 2-h intervals between each test. To simulate cycling, the participants viewed a screen positioned approximately 5 m in front of them at eye level while cycling and repeated the information on the screen (e.g., as a sentence) to confirm that they received this information. The information was randomly displayed on the screen at a rate of approximately six times per minute.

2.7. Statistical analysis

This study used SPSS 17.0 statistical software for the statistical analyses. The statistical significance level was set at 0.05, and each participant was considered a block. Two-factor analysis of variance (ANOVA) was performed to determine the effects of the independent variables on the dependent variables (i.e., body posture, subjective discomfort rating, and stability scores), and Duncan's multiple-range test (Duncan's MRT) was conducted for post hoc comparisons. In addition, a Pearson product–moment correlation was used to explore the PNL and subjective discomfort rating values and the test–retest reliabilities.

3. Results

In the tests, the participants repeated each experimental combination twice on distinct days. The ANOVA results indicated that the repetition effects on the various dependent variables were not significant (all $p > .05$). The intraclass correlation coefficient (ICC) values for the reliabilities between the repeated trials performed on distinct days ranged from 0.87 to 0.96 (all $p < .01$) for each dependent variable among the 16 participants.

3.1. Effects of handles on the cycling posture

The ANOVA results indicated that handle heights (from straight to dropped) significantly influenced cycling posture (as shown in Table 2), including the anterior torso tilt (difference of 16.7°), increasing the severity of lumbar kyphosis (difference of 6.3°). Because the test simulated a normal sight level during riding, when the torso tilted forward, a greater HE was required. Regarding the PT relative to the TA, the dropped handles reduced the PT (difference of 7.7°). In other words, lower handles caused the torso to lean forward; in addition to pelvic anterior rotation, additional spinal curvature (approximately 9.0°) was required for cycling.

3.2. Effects of handle heights on subjective discomfort and stability

Table 3 shows the ANOVA and Duncan test results for the effects of handle variables on the subjective discomfort and stability scores. In the table, dropped handles caused a high subjective discomfort rating value for the neck/shoulders, wrists, and lower back (all $p < .001$). Among these, the wrists had the highest discomfort value (6.88), whereas the lower back had the lowest (3.06). The subjective discomfort levels experienced in the perineum and ischial tuberosity were not affected by handle height. In addition, the table also indicates that dropped handles caused poor stability ($p < .01$).

3.3. Effects of PNL on cycling posture

Table 4 indicates that different PNLs affected only the TA ($p < .01$), and did not affect the other body angles. When the PNL was shortened, the torso had a greater anterior tilt angle within a range from 38.0° (when PNL = 12 cm) to 44.1° (when PNL = 0). The Duncan MRT results indicated that the trunk of the rider flexed more significantly ($p < .01$) when the PNL was short (0 and 3 cm) rather than when the PNL was long (9 and 12 cm).

Table 2
ANOVA and Duncan MRT for the effects of handlebars on cycling postures (unit in degrees).

Variables	N	DF	F	p value	Handles	Mean (SD)	Duncan groups
Torso angle	160	1	1525.2	$p < .001$	Straight	33.1 (3.8)	A
					Dropped	49.8 (3.9)	B
Pelvic tilt	160	1	342.0	$p < .001$	Straight	41.3 (5.4)	A
					Dropped	33.6 (4.8)	B
Lumbosacral angle	160	1	79.5	$p < .001$	Straight	−4.3 (4.6)	A
					Dropped	−10.6 (5.8)	B
Head extension	160	1	92.3	$p < .001$	Straight	1.4 (10.9)	A
					Dropped	13.5 (11.2)	B

Table 3
ANOVA and Duncan MRT for the effects of handlebars on subjective scores of discomfort and stability.

Variables	N	DF	F	p value	Handles	Mean (SD)	Duncan groups
Discomfort on							
Neck/shoulders	160	1	156.7	$p < .001$	Straight	2.24 (1.26)	A
					Dropped	4.83 (2.28)	B
Wrist	160	1	91.6	$p < .001$	Straight	4.34 (2.05)	A
					Dropped	6.88 (2.57)	B
Lower back	160	1	38.1	$p < .001$	Straight	2.06 (1.15)	A
					Dropped	3.06 (1.69)	B
Perineum	160	1	1.0	0.968	–	–	–
Ischial tuberosity	160	1	0.8	0.978	–	–	–
Stability	160	1	6.7	$p < .01$	Straight	2.95 (1.91)	A
					Dropped	3.66 (2.26)	B

3.4. The effects of PNL on subjective discomfort and stability

The PNL and the handle-height variables exhibited an opposite trend on subjective discomfort ratings (as shown in Table 5). Table 5 shows that the PNL significantly influenced only the subjective discomfort scores of the perineum ($p < .01$) and the ischial tuberosity ($p < .05$), and did not affect the other body parts. The results showed that the PNL had significantly positive and negative correlations with the discomfort scores of the perineum ($r = 0.994$, $p < .005$) and ischial tuberosity ($r = -0.914$, $p < .05$), respectively. Regarding stability, the participants indicated that short PNLs (0 and 3 cm) were significantly less stable ($p < .001$) than were long PNLs (6–12 cm).

4. Discussion

Previous studies have not conducted systematic research on the PNLs of bicycle seats. This study measured the body posture and subjective rating values for various handle-height and PNL combinations to determine the optimal PNL. The results of this study were consistent with our expectations. Varying the PNLs affected the riding TA and caused a trade-off in discomfort between the perineal and ischial tuberosity regions. If cycling stability is the primary consideration, we suggest that the 6-cm PNL is the optimal seat design.

The results indicated that various handle heights led to significant differences in the subjective discomfort scores of the neck/shoulders, wrists, and lower back, but not for the perineum and ischial tuberosity (as shown in Table 3). Conversely, various PNLs significantly influenced the discomfort level for the perineum and ischial tuberosity, but had no effect on the other body parts (as shown in Table 5). Fig. 3 shows that the discomfort scores for the perineum and ischial tuberosity had positive ($r = 0.994$, $p < .005$) and negative ($r = -0.914$, $p < .05$) correlations with the PNL, respectively. In other words, the traditional seat (PNL = 12 cm) and

Table 4
ANOVA and Duncan MRT for the effects of protruding node length (PNL) on cycling posture (unit in degrees).

Variables	N	DF	F	p value	PNL (cm)	Mean (SD)	Duncan groups
Torso angle	64	4	7.7	$p < .01$	0	44.1 (9.5)	A
					3	43.7 (9.2)	A
					6	42.2 (9.9)	A B
					9	39.8 (8.1)	B
					12	38.0 (7.4)	B
Pelvic tilt	64	4	1.1	0.377	–	–	–
Lumbosacral angle	64	4	0.4	0.816	–	–	–
Head extension	64	4	0.2	0.974	–	–	–

Table 5
ANOVA and Duncan MRT for the effects of protruding node length (PNL) on subjective scores of discomfort and stability.

Variables	N	DF	F	*p* value	PNL (cm)	Mean (SD)	Duncan groups
Discomfort on							
Neck/shoulders	64	4	1.0	0.419	–	–	–
Wrist	64	4	0.8	0.524	–	–	–
Lower back	64	4	0.4	0.824	–	–	–
Perineum	64	4	3.1	$p < .05$	0	3.88 (2.11)	A
					3	4.20 (2.09)	A B
					6	4.52 (1.82)	A B C
					9	4.76 (1.92)	B C
					12	5.02 (1.74)	C
Ischial tuberosity	64	4	3.6	$p < .01$	0	5.13 (2.03)	A
					3	4.60 (2.12)	A B
					6	4.42 (2.09)	A B
					9	3.85 (1.87)	B
					12	3.85 (1.72)	B
Stability	64	4	6.7	$p < .001$	0	4.36 (2.10)	A
					3	4.07 (2.27)	A
					6	3.00 (1.68)	B
					9	2.64 (1.92)	B
					12	2.61 (2.08)	B

non-PNL seat may generate greater discomfort in the perineum and ischial tuberosity, respectively. Fig. 3 shows that the sums of the discomfort scores for these two body regions remained nearly unchangeable. How discomfort can be appropriately distributed between the perineum and ischial tuberosity regions may depend on the PNL.

The trade-off in discomfort between the perineum and the ischial tuberosity may be partially attributed to the cycling posture, especially pelvic rotation. Varying the PNLs affected the TA (Table 4), which ranged approximately 6° from 38.0° (when PNL = 12 cm) to 44.1° (with no PNL). Bressel and Larson (2003) determined that bicycles seats lacking a PNL tend to cause the torso to lean forward; this is consistent with the current results. However, no significant change for the PT was observed (approximately unchangeable 37°). In this study, the PT was defined as the tilt angle relative to the TA (Fig. 2). The torso gradually leaned forward when using a seat that exhibited a short PNL, possibly because of the anterior rotation of the pelvis. During movement, the torso and pelvis can be regarded as a whole. The pelvic anterior rotation directly affected the contact pressure between the seat surface and the perineum and ischial tuberosity, leading to differences in discomfort scores. This can also be attributed to weight

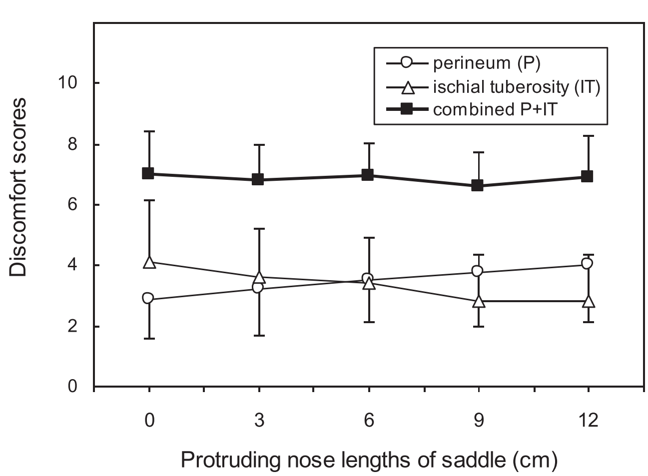

Fig. 3. Perineum and ischial tuberosity discomfort ratings (mean ± SD) when applying various PNLs.

distribution changes caused by the anterior tilt of the torso; however, the influence was limited because the change in torso tilt was relatively small.

The handlebar height variable had a different effect on the movement of the torso and pelvis than did the PNL variable. Table 2 shows that the handle height significantly influenced both the TA and PT. The anterior torso tilt increased by 16.7° when using a low handle height, causing greater lumbar kyphosis (+6.3°). Varying the handle heights caused a PT difference of 7.7°. Consequently, an insufficient movement of 9.0° existed between the TA and the PT. This insufficient movement must be compensated by curving the spine, thus increasing the severity of lumbar kyphosis. In other words, the torso tilted forward at low handle heights could be completed by the spine and pelvic anterior rotation. However, the spine seemed to contribute more than the pelvis did, possibly because of the seat restriction.

Because of the differences in perineal anatomy, pelvic bone geometry, and segmental center of gravity (Bressel et al., 2009), the effect of PNL on cycling behaviors between genders merits further investigation. Furthermore, the differences in seat design must be examined for each gender because the width of the ischial tuberosity differs between male and female bicyclists (Potter et al., 2008). In this study, only male participants were recruited for the tests and the seat width was considered a controlled variable (i.e., 16 cm). In addition to the seat width, other cycling variables were controlled during the experiments. For example, the pedaling load and cadence were set at constant levels (i.e., 60 rpm at an external workrate of 120 W) although various workloads and cadences can affect the joint angles of riders (Peveler et al., 2012). The saddle inclination, which may affect groin discomfort (Burke, 1994), was set horizontally. Furthermore, the saddle height determined based on the leg length of the rider differed between cyclists. Whether the PNL combines with other cycling settings to affect cycling behaviors requires further examination.

Using seats with short PNL or without protruding nodes afforded the participants a greater range of pelvic anterior rotation. Although the seats with short PNLs caused each participant's torso to tilt forward, the pelvis could be anteriorly rotated entirely. Bressel and Larson (2003) found that, not only do seats without a protruding node increase the anterior tilt of the torso, but the pelvic anterior rotation angle also increases by approximately 16% compared with that of traditional seats. In addition, the pelvic angle employed by Bessel and Larson was defined as the intersection angle of the ASIS-PSIS (ASIS, anterior superior iliac spine; PSIS, posterior superior iliac spine) connection line to the horizontal. When the PT excluded the trunk angle, the forward tilting angle of the torso was contributed almost entirely by the pelvic rotation in various PNL conditions. This movement pattern was considerably different from the forward trunk tilt caused by reducing the handle height, which was completed by both curving the spine and rotating the pelvis.

In the analysis, the participants felt more unstable cycling with the dropped handles than with the straight handles (scores 3.66 : 2.95). When PNL was ≤3 cm, the instability of riding was significantly higher than when using other PNLs. Fig. 4 shows that differences in cycling stability between the two handle types. The Duncan MRT result indicated that, when PNL ≥6 cm, the handle height did not affect the stability. Conversely, when the participants were cycling with a seat PNL = 0 or 3 cm, the dropped handles were more unstable than the straight handles. This implied that, in low handle height conditions, short protruding nodes (0 or 3 cm) should not be used to prevent cycling safety concerns such as instability. By considering both discomfort in the perineum and ischial tuberosity and perceived stability, this study suggests that 6-cm PNLs should be used as a reference for bicycle seat designs. Furthermore, the advantages of seats exhibiting 6-cm PNLs should

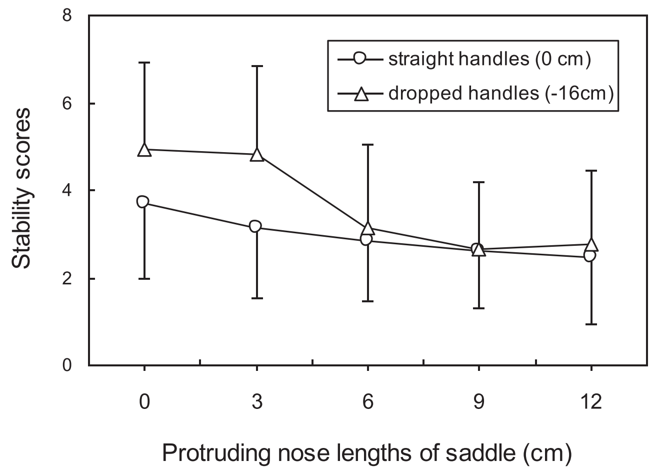

Fig. 4. Cycling stabilities (mean ± SD) at various PNLs and handle heights.

be validated using 3D motion analyses, for example examining lateral pelvic sway, and the potential pressure distribution assessment on saddles.

5. Conclusion

No previous study has systematically examined the effects of PNL on cycling posture, body discomfort, and cycling stability. This study collected data on the body postures and subjective rating values at various seat PNLs and handle heights. The results showed that, when the PNL = 6 cm, the discomfort between the perineum and ischial tuberosity regions achieved a favorable distribution, subsequently providing a sufficient degree of stability for the rider. In addition, we observed that the pelvic rotation differed at various handle and PNL variables. This may be crucial for the differences in body discomfort and stability, and require further clarification.

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